GLAS Instrument & Lasers on the ICESat Mission

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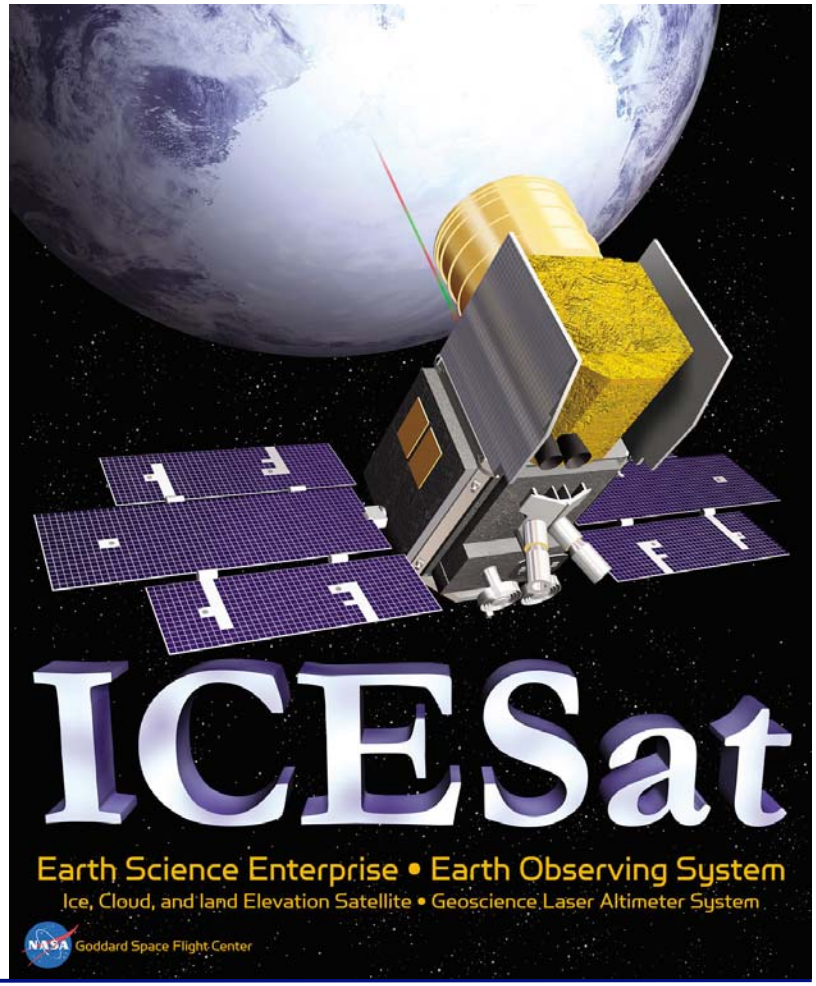
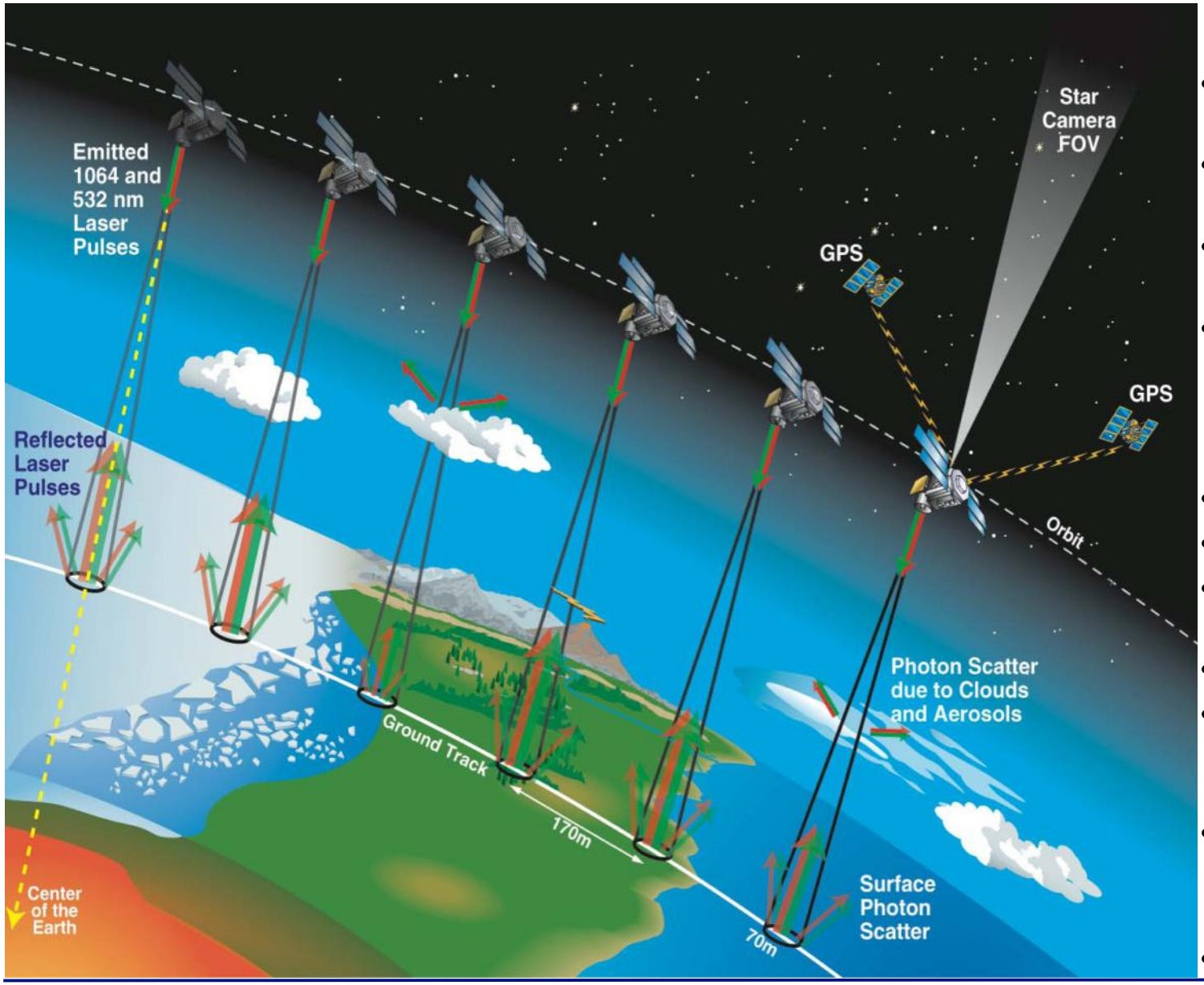


1. Measurement Approach



Science Objectives:

- Polar ice-sheet elevation changes and mass balance
- Atmosphere-cloud heights and aerosol distribution
- Land topography and vegetation
- Sea ice characteristics

GLAS measures for each laser pulse:

- 3-6 cm ranging to surface
- Echo pulse waveform
- 75 m sampling within atmosphere
- Precise (2 arcsec) pointing
- 5-10 cm orbit accuracy

Mission Context:

- Medium Cost-Medium Risk Instrument

Launch:

- January 12, 2003

1. Science Measurements

1. Surface Altimetry:

- Range to ice, land, water, clouds
- Time of flight of 1064 nm laser pulse
- Digitizes transmit & received 1064-nm waveforms
- Resolutions: 1 nsec for digitizer
- Noise floor in altimetry: ~ 2.4 cm

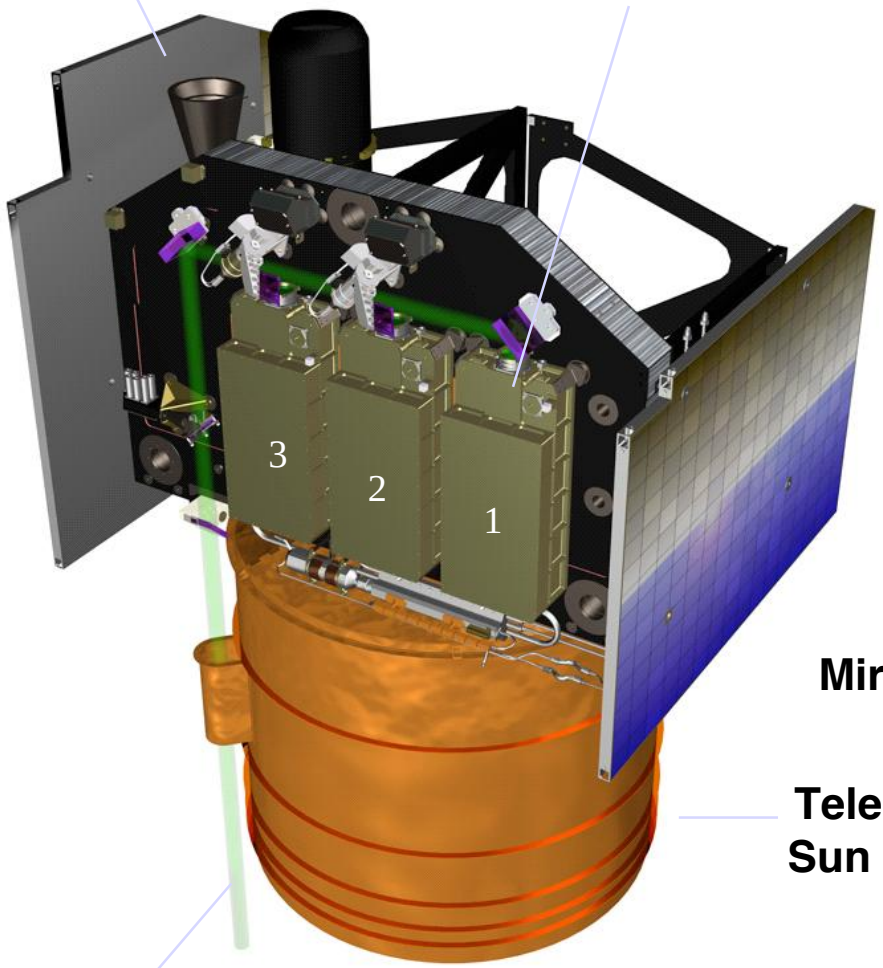
2. Laser pointing:

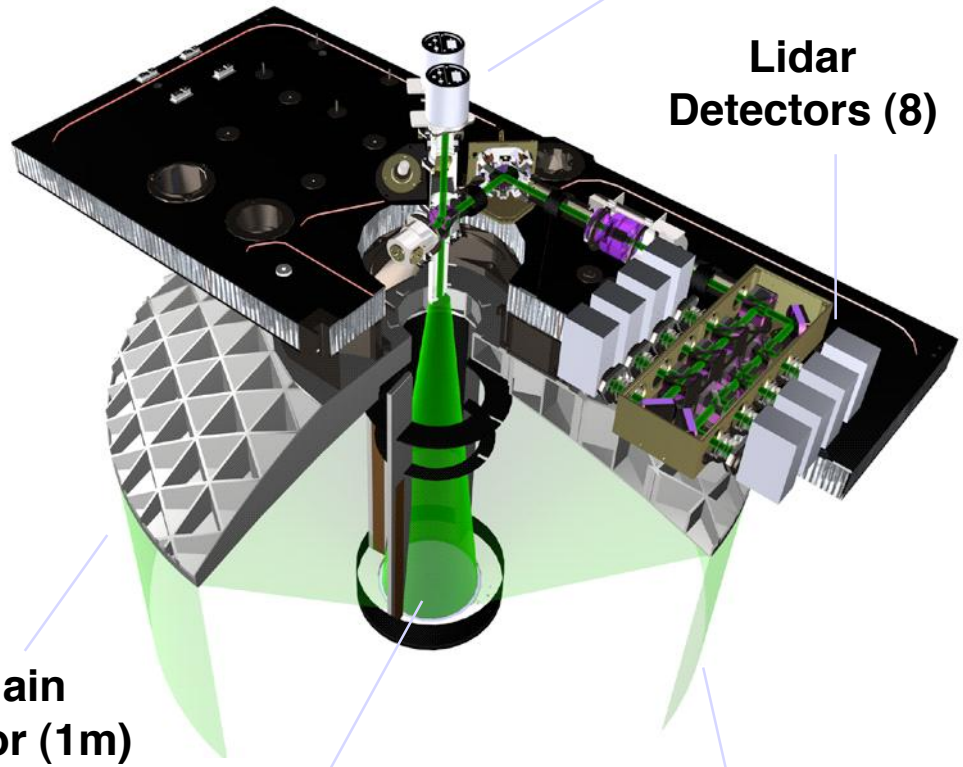
- Laser-beam pointing from star-trackers, laser camera & gyro
- <10 cm single shot range resolution
- <1.5 arcsec angular resolution

3. Atmospheric lidar:

- Laser back-scatter profiles from clouds & aerosols
- Uses 1064 nm & 532 nm pulses
- 75 m vertical resolution
- Analog (1064 nm) photon counting (532nm) detection
- Simultaneous, co-located measurements with altimeter

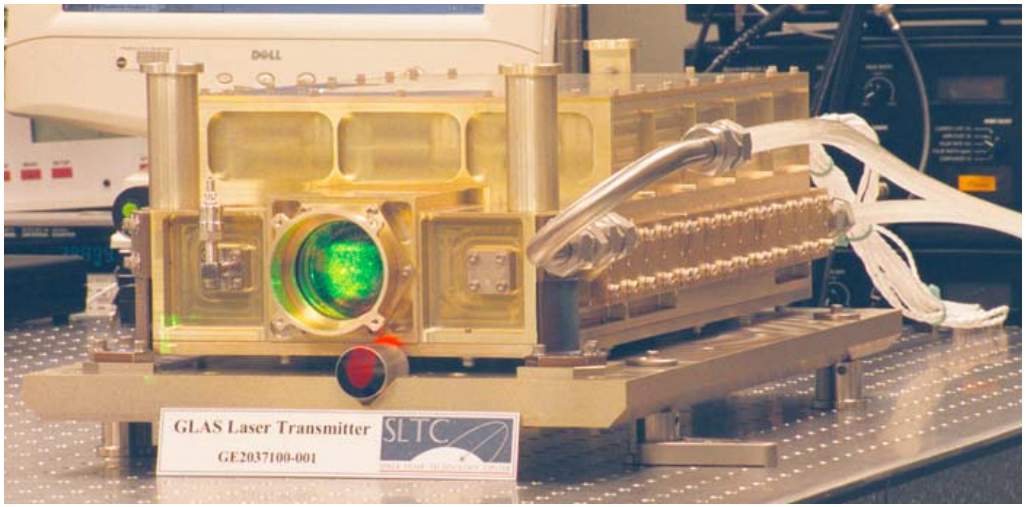
1. GLAS Instrument





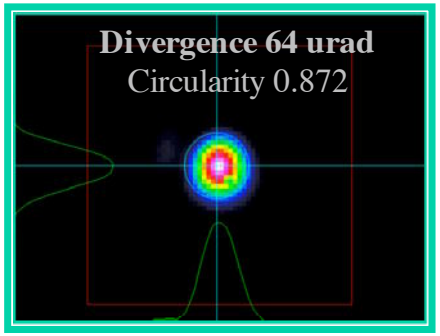
Graphics courtesy of GLAS Instrument Team
(not to same scale)

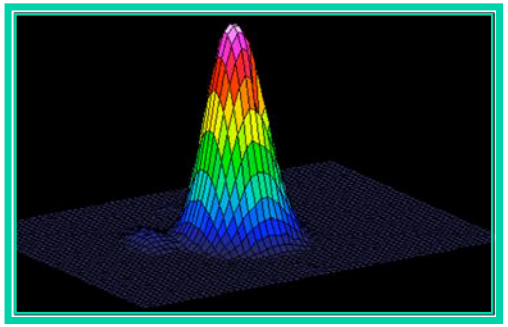
2. GLAS Flight Lasers



GLAS Lasers:

3 stage, passively q-switched, 2 color
Designed & built by GSFC
3 flown, flight spare, ETU, several breadboards

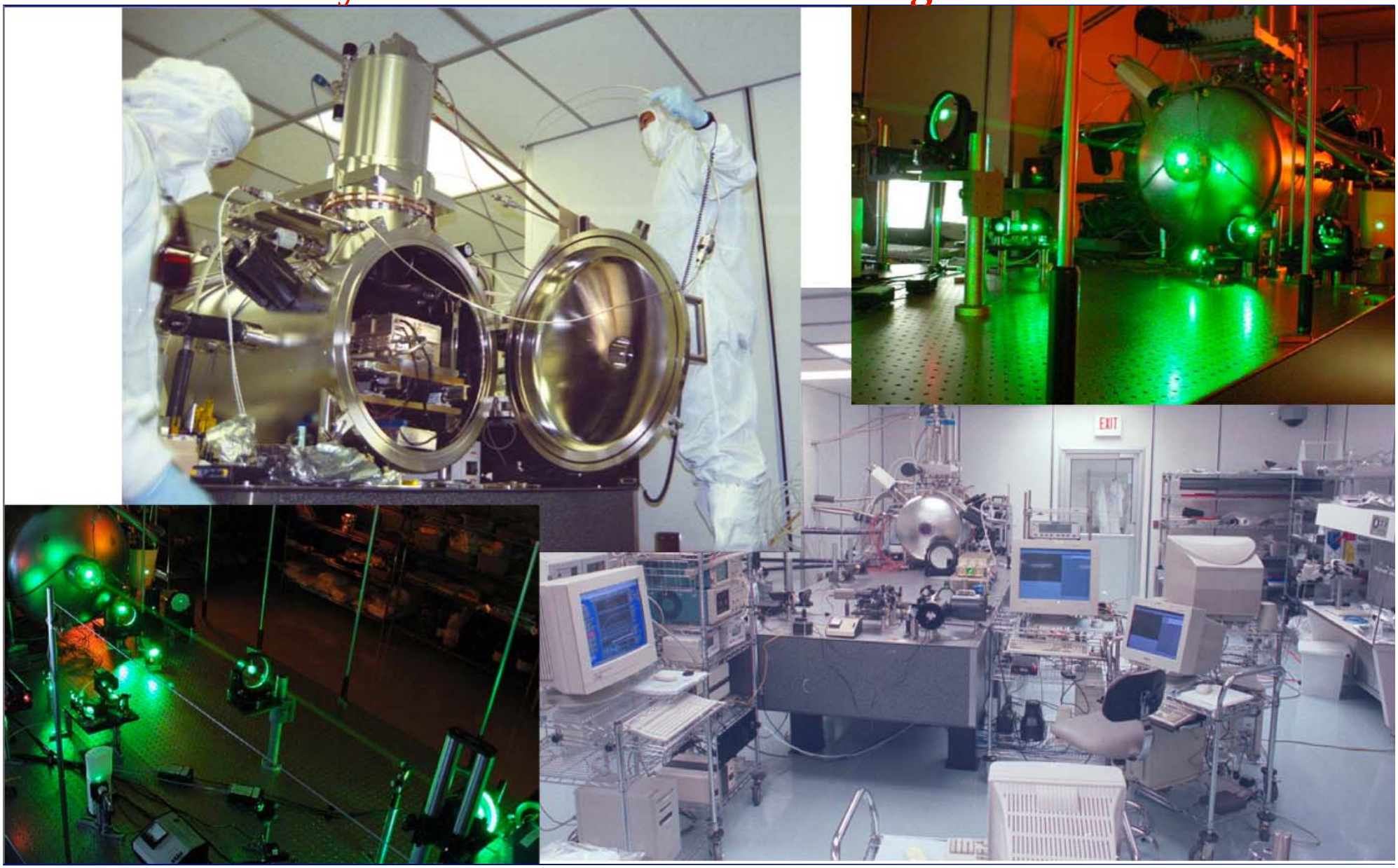




Diode Pumped Passively Q-Switched Nd:YAG Laser

Pulse energy:	102mJ
532.25 nm:	32 mJ
1064.5 nm:	70 mJ
Pulse rate:	40Hz
Ave. optical power:	4.1Watts
Pulse width:	6 nsec
Linewidth:	<1.5 pm
Beam divergence:	70-110 urad
Spatial mode:	Quasi-gaussian
Pointing jitter:	< 25urad
Electrical power (30V):	110Watts
Mass (incl power convert.):	15.1 kg
Size:	54x15x25 cm^3

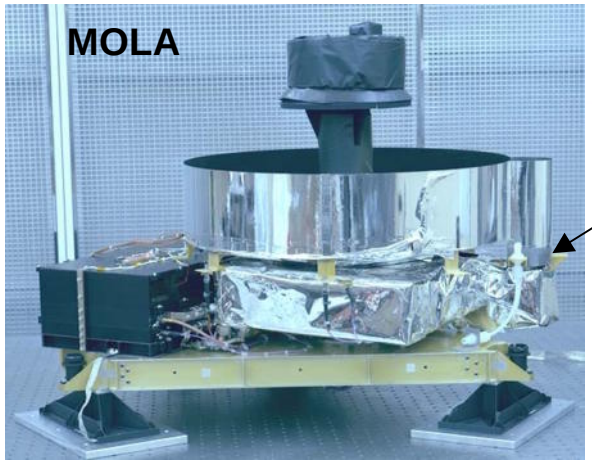
2. Flight Lasers for GLAS
Assembly & Thermal Vacuum Testing at SLTC



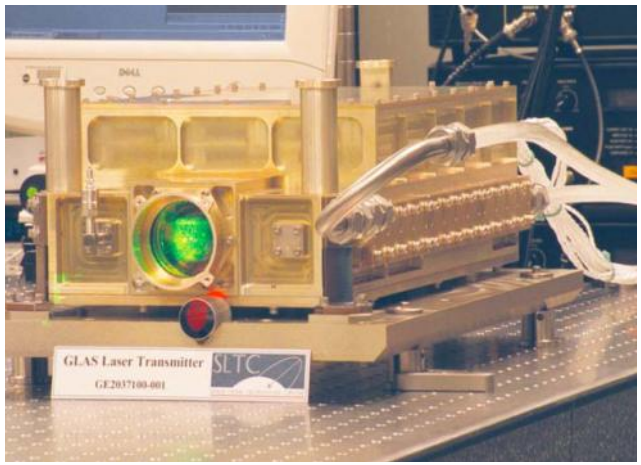
2. GLAS Flight Laser Firings (Millions) through 6/25/06

	Laser 1	Laser 2	Laser 3	TOTAL*	% of Mission Goal (3,784M)	Comparison to MOLA
Ground Testing*	158.8	140	128.8	427.6	11%	63% on orbit measurements
On-Orbit*	126.8	417.5	699**	1243	33%	185% of MOLA
TOTAL*	285.6	557.5	828	1671		
Status	Failed	Off	In Operation			

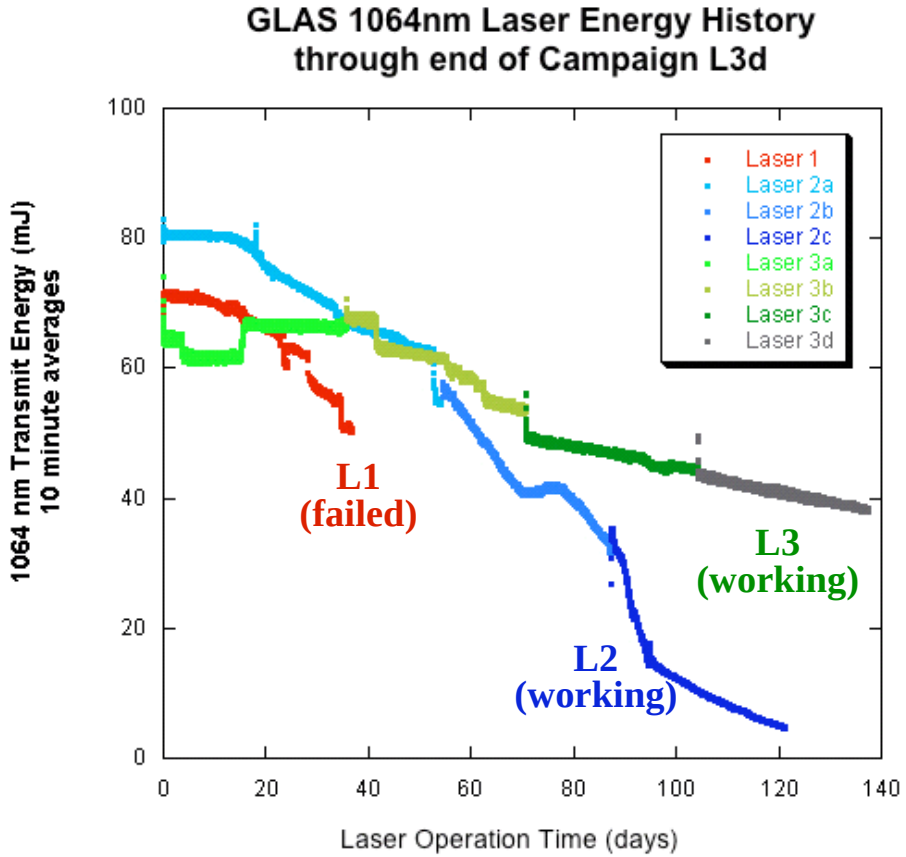
*Millions of shots

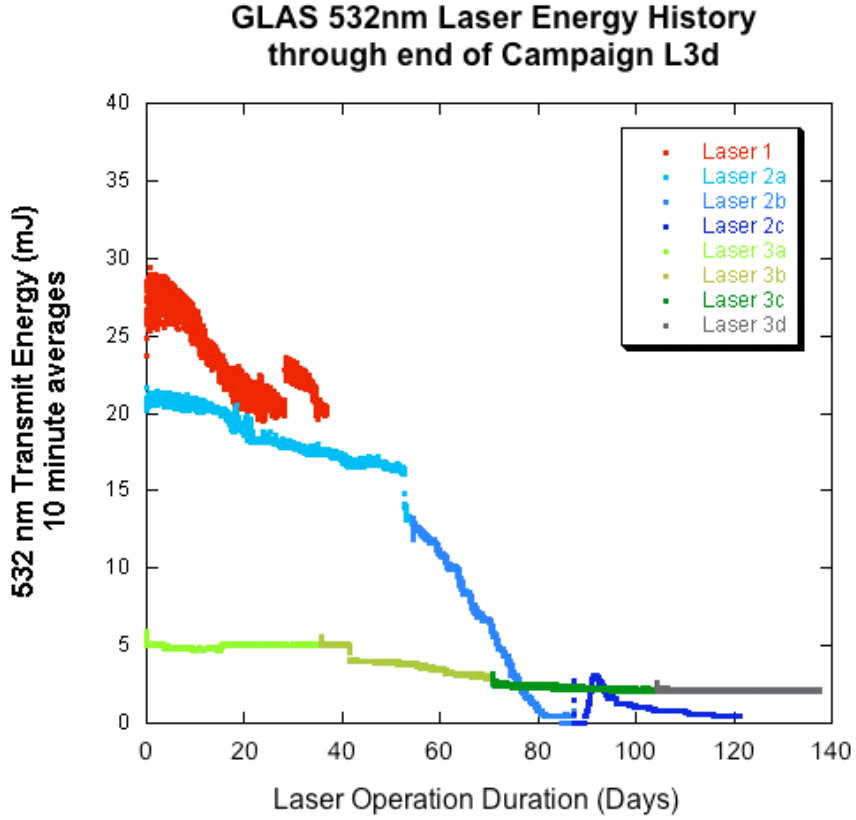


** -MOLA Laser Total (previous record): = 673 million



2. GLAS Lasers:
All Energy Histories through end of L3d





Present Understanding:

L1 - (31C) - failed - pump array part "bar blowout"/gold indide, impacted by photodarkening

L2 - (25 & 16C) - energy impacted by photodarkening

L3 - (14C) - some impact on change rate from "bar drops"

2. GLAS Lasers - pump diode parts issue

GLAS Laser Heritage and Testing

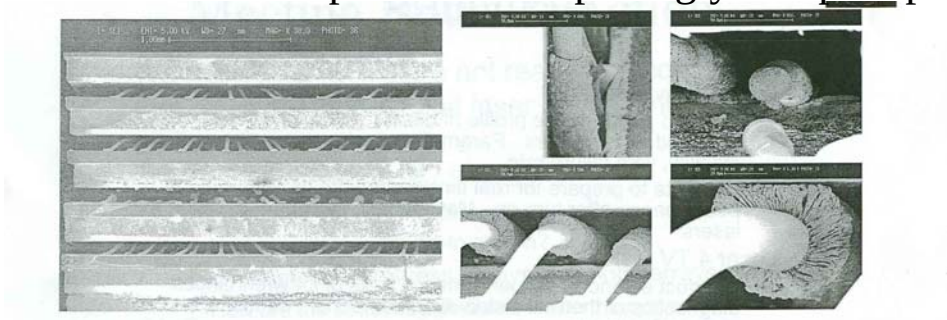
- GLAS pump diodes & osc stage tested for 3-6 billion pulses
- Pump arrays were selected versions of commercial parts
- Used de-rated (less drive current than commercial spec)
- Gold-indide defect was latent
  - Did not surface in life- or pre-launch tests

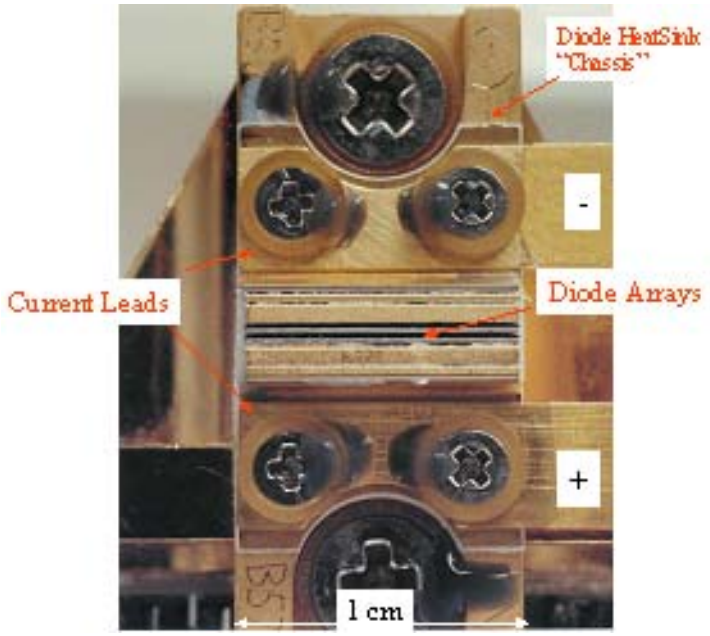
GLAS Anomaly Review:

- Laser 1 failure was from a parts problem
  - Vendor's use of indium in diode pump array assembly, leading to gold erosion & bond wire failure
- Laser 2 energy decay likely from slow contamination

Programmatic:

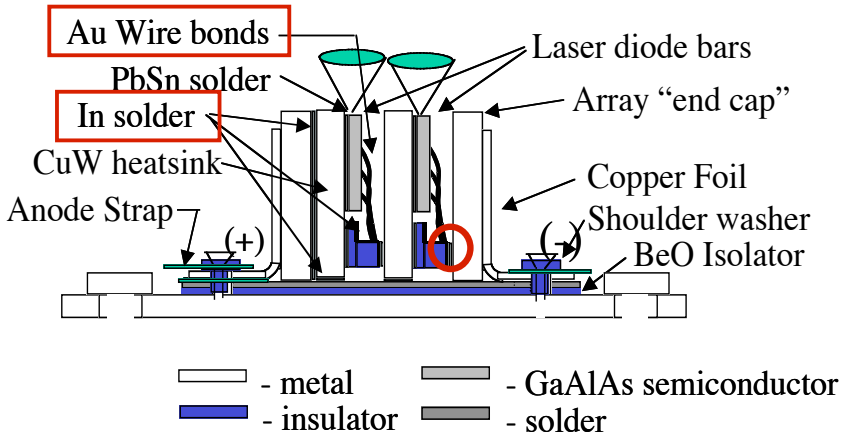
- GLAS was Class C instrument with Grade 3 parts program
- One vendor for an expensive & surprisingly complex part



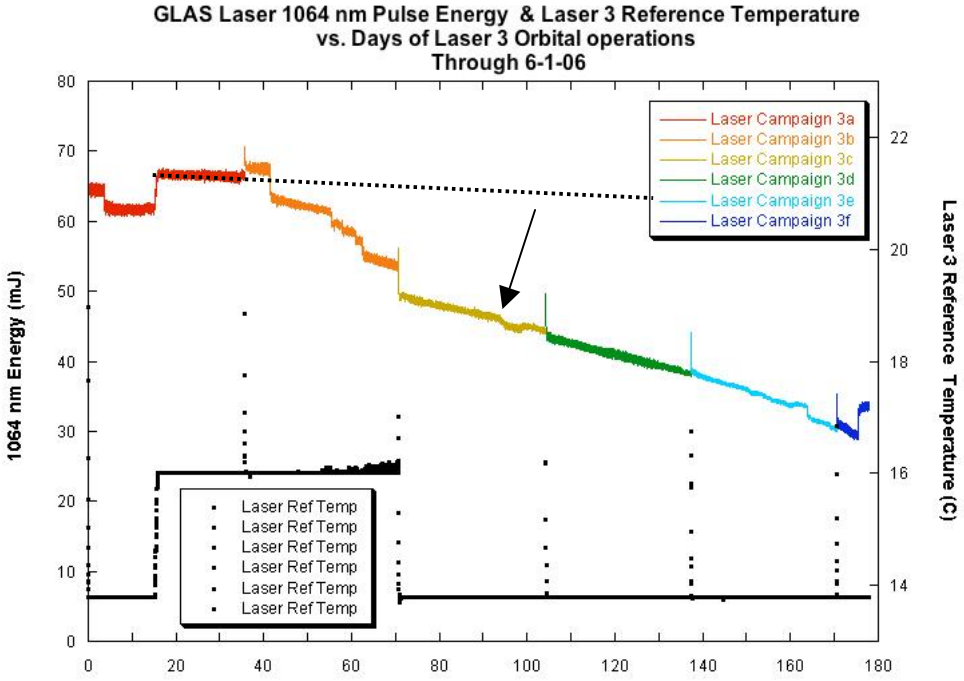


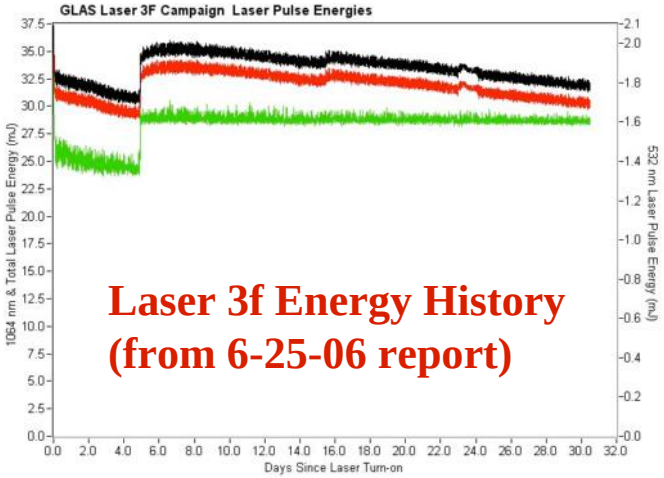
SDL 100W diode array (G2)

Side sketch

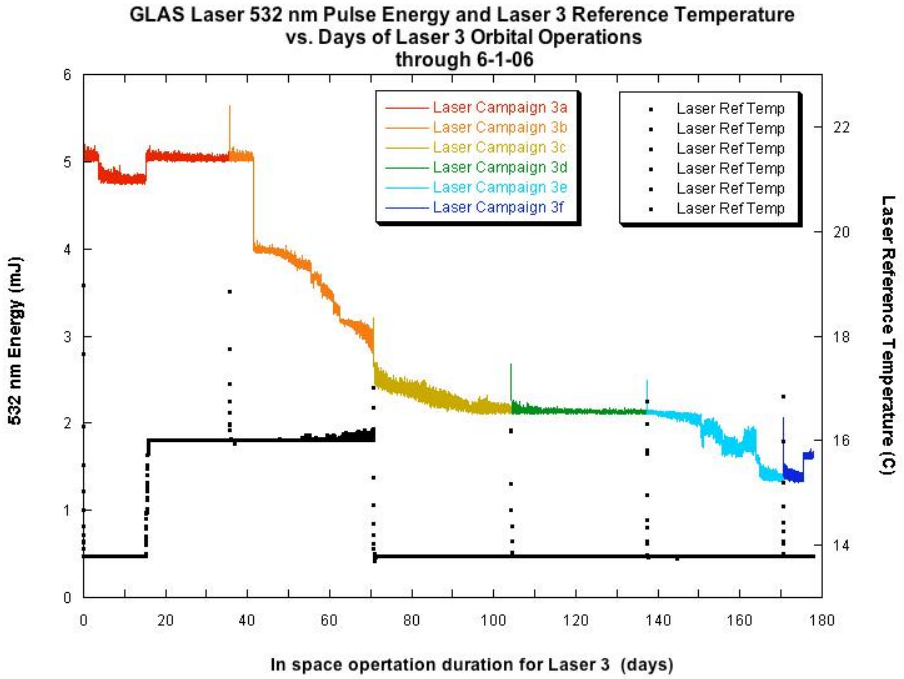


2. GLAS Laser 3 Energy History





Laser 3f Energy History (from 6-25-06 report)



Laser 3:

- Operated on 6 campaigns so far
- Presently at 702 M shots and 50% energy
- 532 nm energy is low - suspect its doubler crystal mechanically shifted
- **Trends extrapolate to 4-5 more campaigns**
- **=> 4 year mission total at 30% duty cycle**

3. Laser Measurements & Operations (10 campaigns so far)

Laser firings through 6/25/06

Total:

GLAS Laser Shot Counter

01,243,219,201

Total number of on-orbit shots emitted by Lasers 1, 2, and 3 since February 2003. ICESat is currently operating in science campaign 3F.

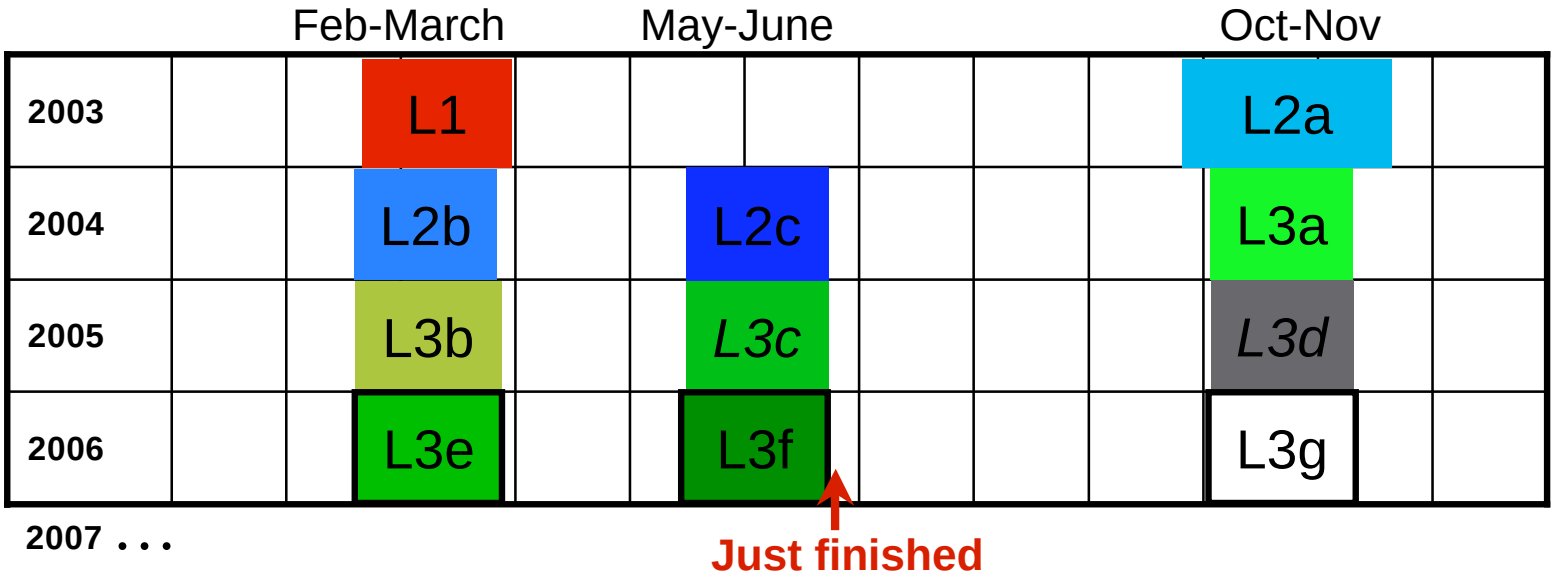
Laser 3:

GLAS Laser 3 Shot Counter

00,698,859,320

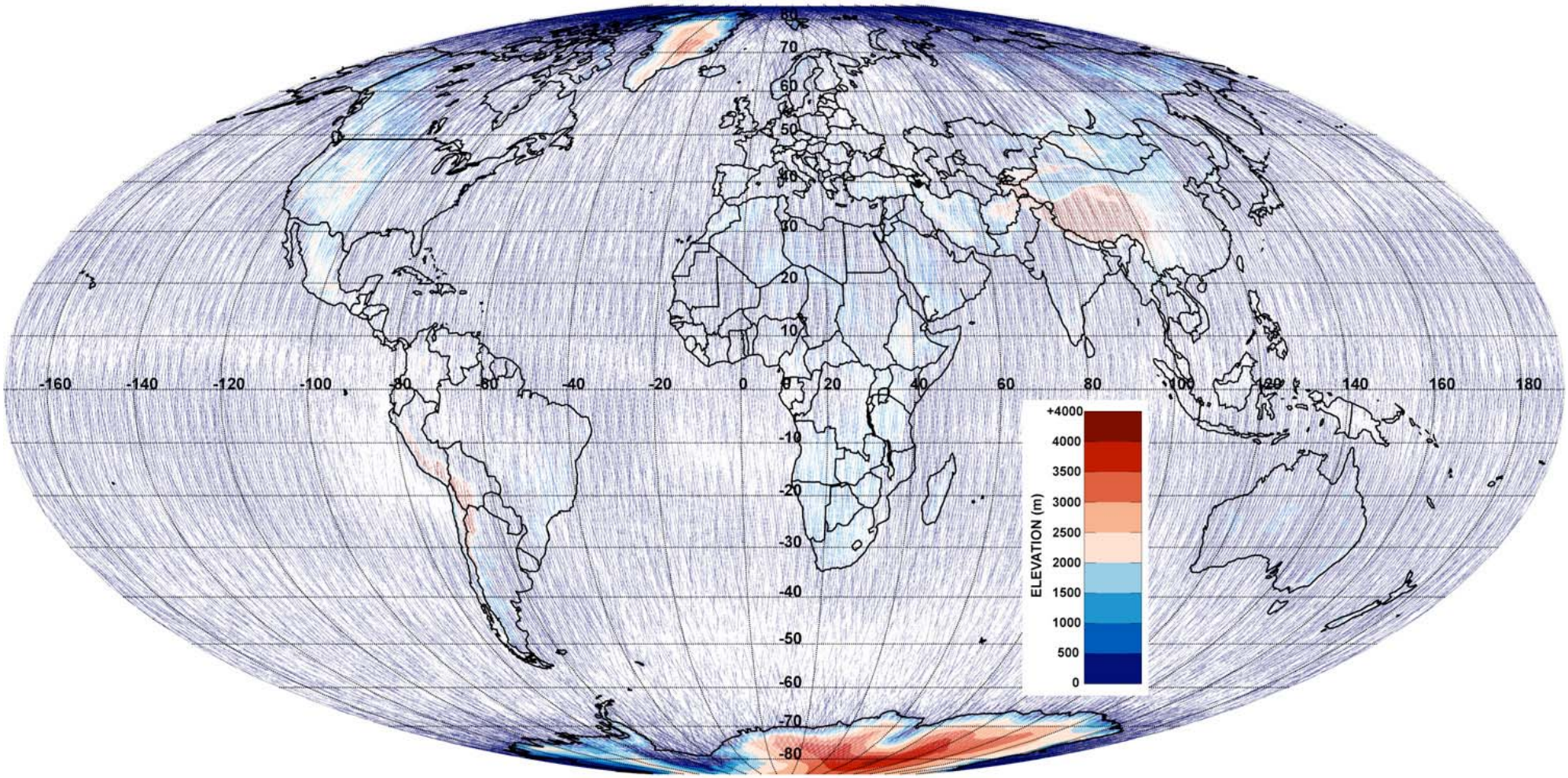
Individual laser pulses shot by GLAS Laser 3 starting on October 3, 2004 and continuing through six science campaigns. Currently, ICESat is operating in science campaign 3F.

ICESat Operating History - 10 campaigns to date

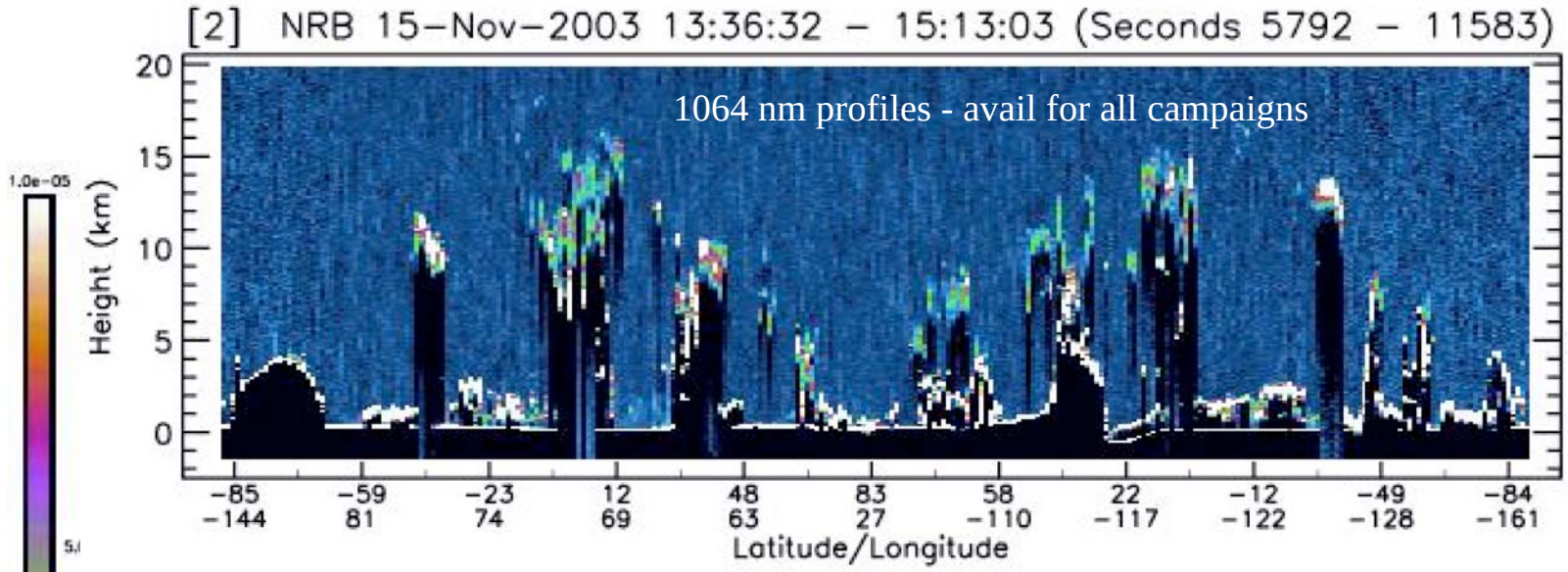


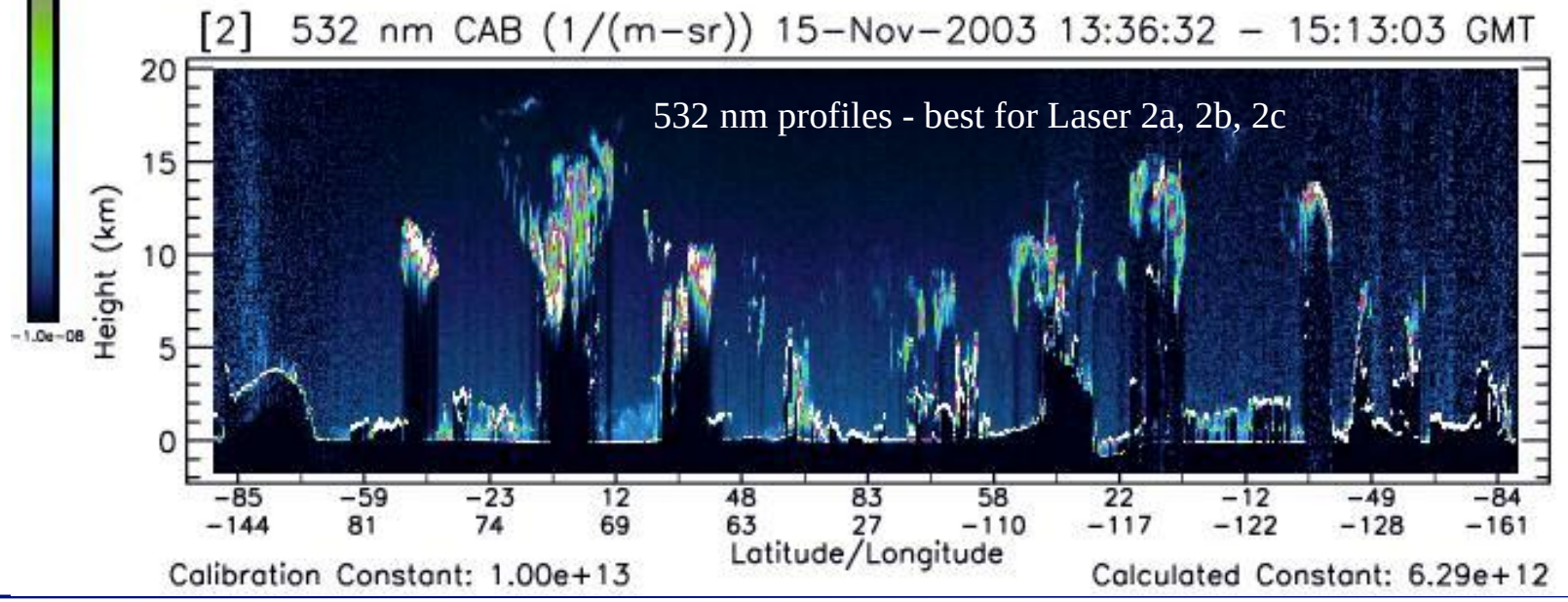
3. Global Altimetry Coverage - Example

ICESat Laser 2a Global Elevation Data - 9/25 to 11/19/03



4. Example of 1064 & 532 nm atmospheric profiles (global)

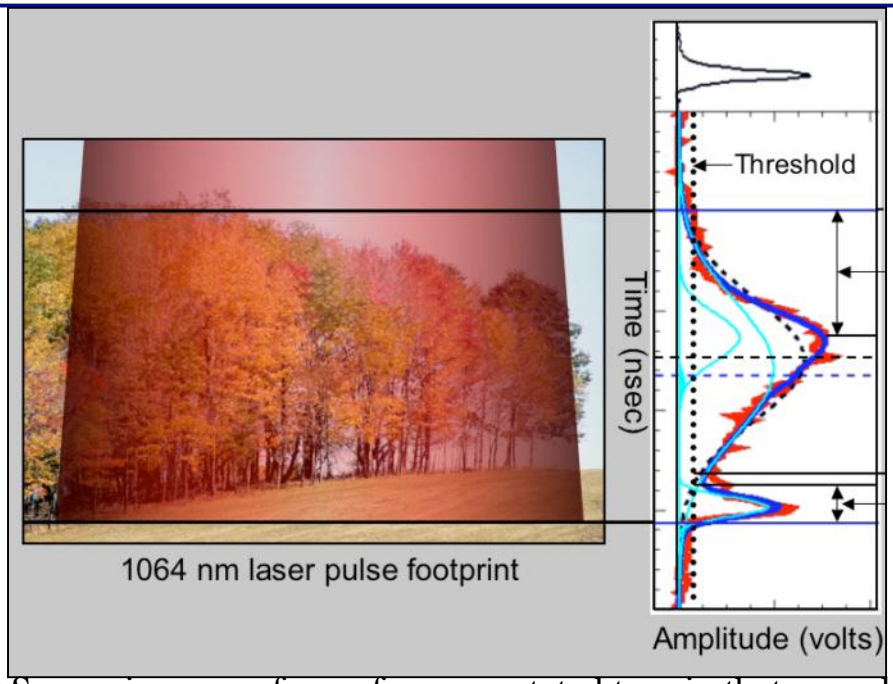


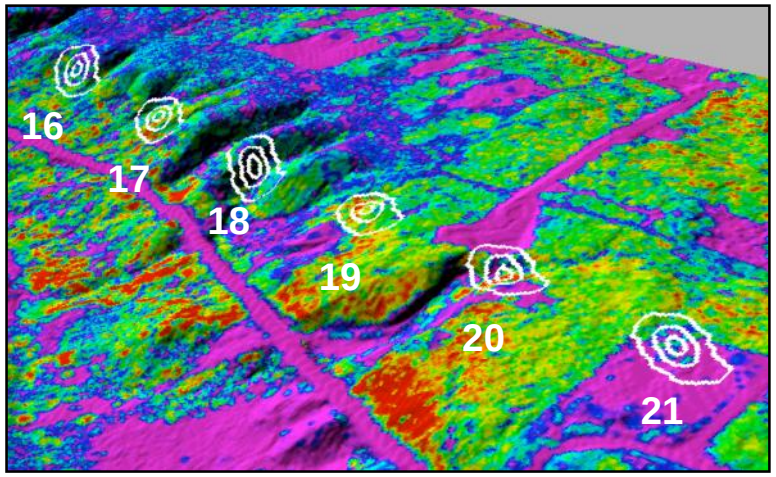


J. Spinhirne
- GSFC

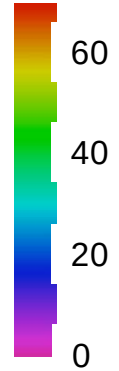
4. ICESat Land Applications

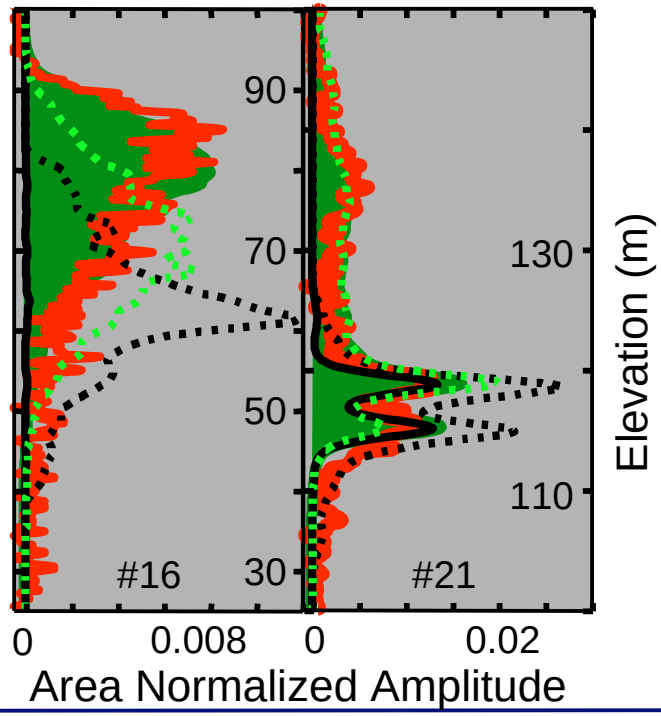
4. Echo Waveforms from Vegetated Terrain





Vegetation Height (meters)





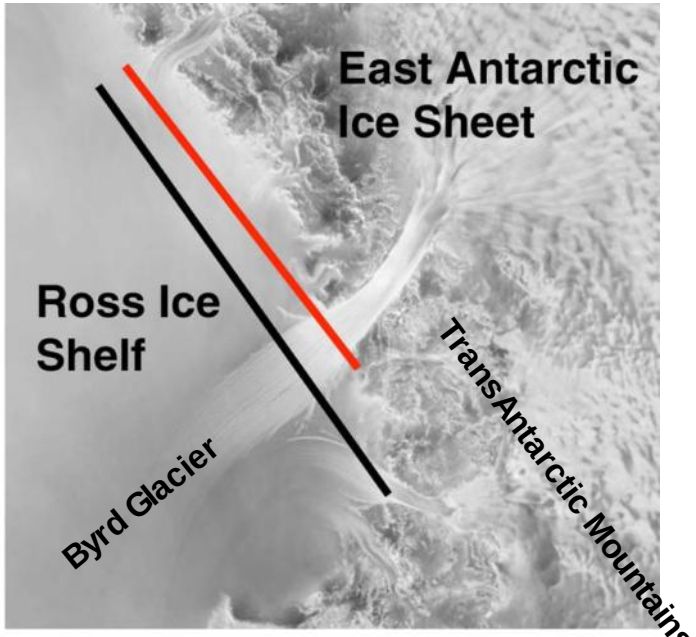
GLAS acquires waveforms from vegetated terrain that record the height distribution of backscattered light reflected from canopy surfaces and underlying ground where illuminated by ~ 70 m diameter laser pulse.

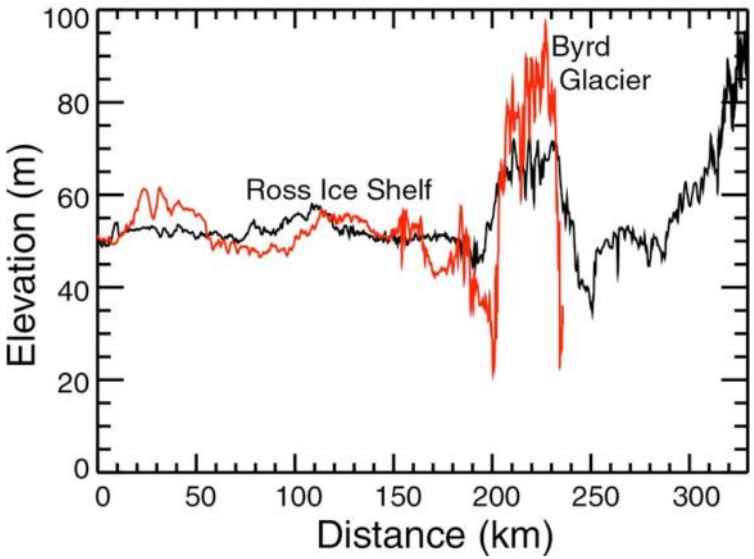
Contours of laser energy (upper-right, white) illustrate 6 GLAS footprints on high-res airborne laser altimeter map of ground elevation & canopy height.

Received waveforms (right, red) compared to synthetic waveforms generated from the airborne data and a GLAS instrument model (dark green: all surfaces; dashed black: "bald" Earth; black: bare ground) validate elevation products and footprint geolocation.

Harding & Carabajal, GRL, 32(21), 2005.

4. Example - Elevation Profile over ice





- Portions of two ICESat profiles show changes to the Byrd Glacier as it flows from East Antarctica, crosses through the TransAntarctic Mountains, and then discharges into the Ross Ice Shelf

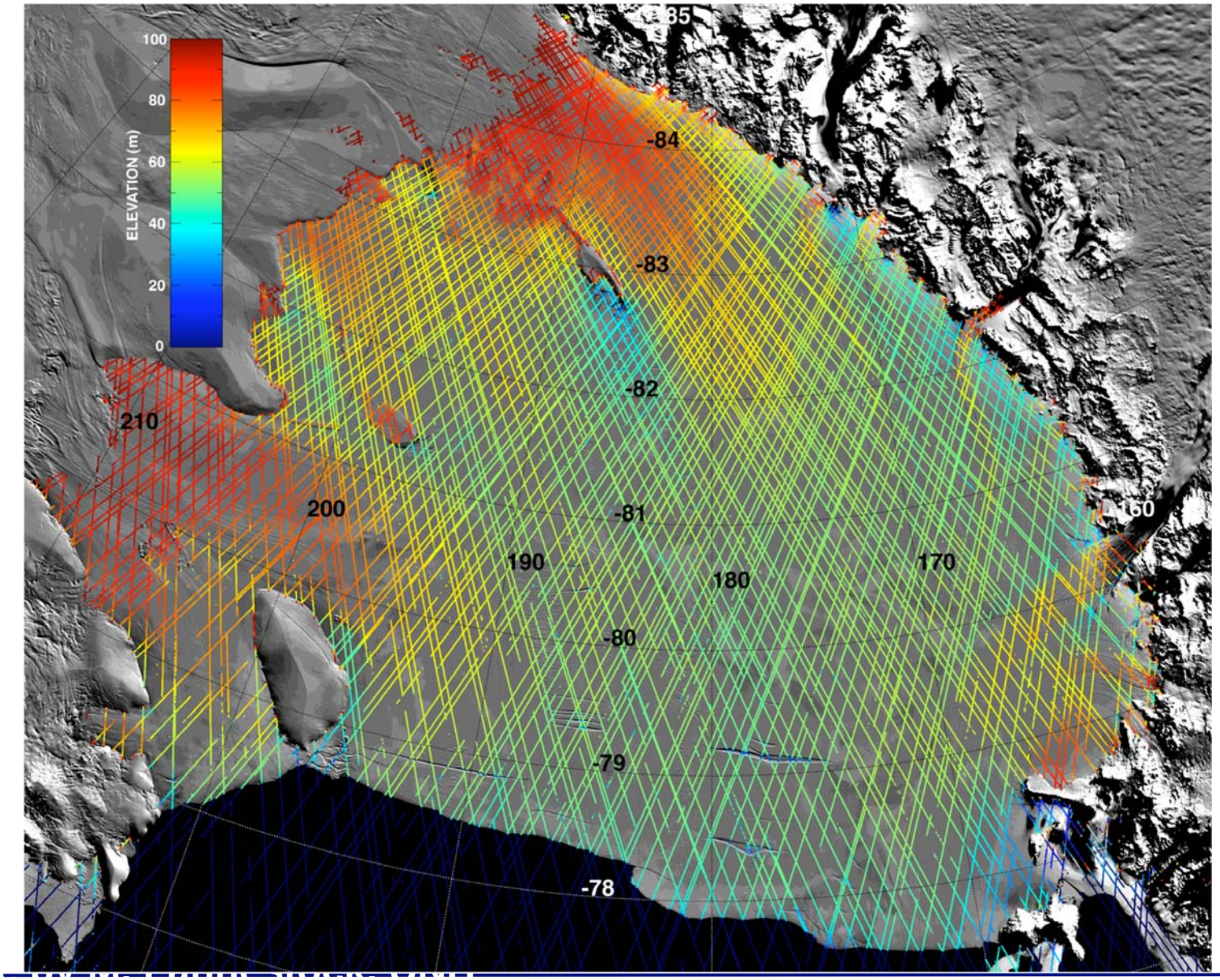
- The red-line, more upstream, shows a thicker, narrower glacier

- The black line (further into the ice shelf) shows that ice flow has caused the Byrd to become wider and thinner

- Rough surfaces, such as crevasses, are also evident

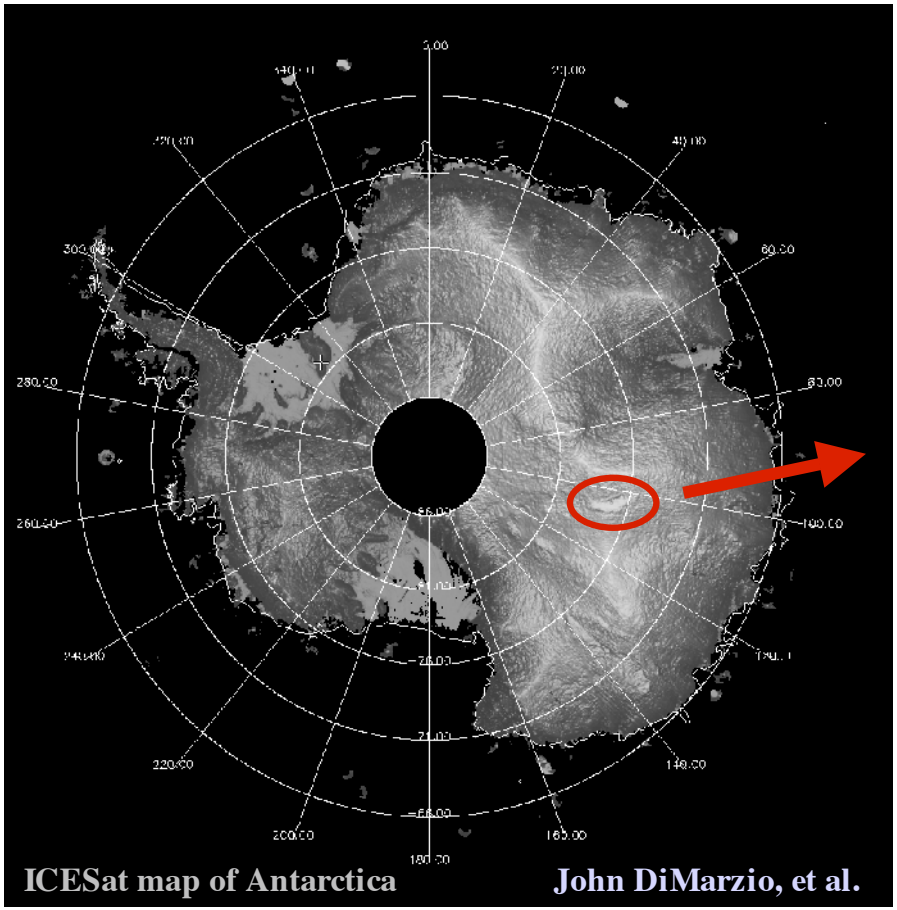
- Never before been observed from space with this degree of vertical and spatial resolution

4. Ross Ice Shelf from ICESat and MODIS (one operating campaign)



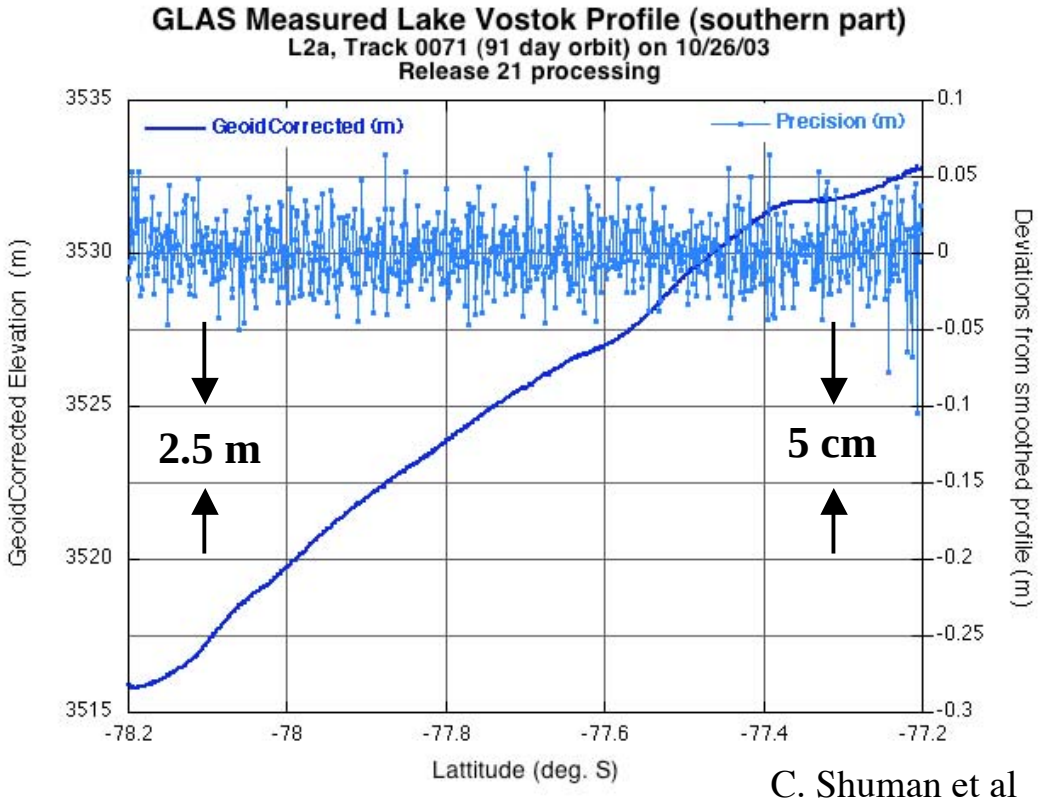
4. GLAS Altimetry Resolution: Measurements to Lake Vostok, Antarctica

On orbit measurements match pre-launch testing. Original Requirement < 10 cm.



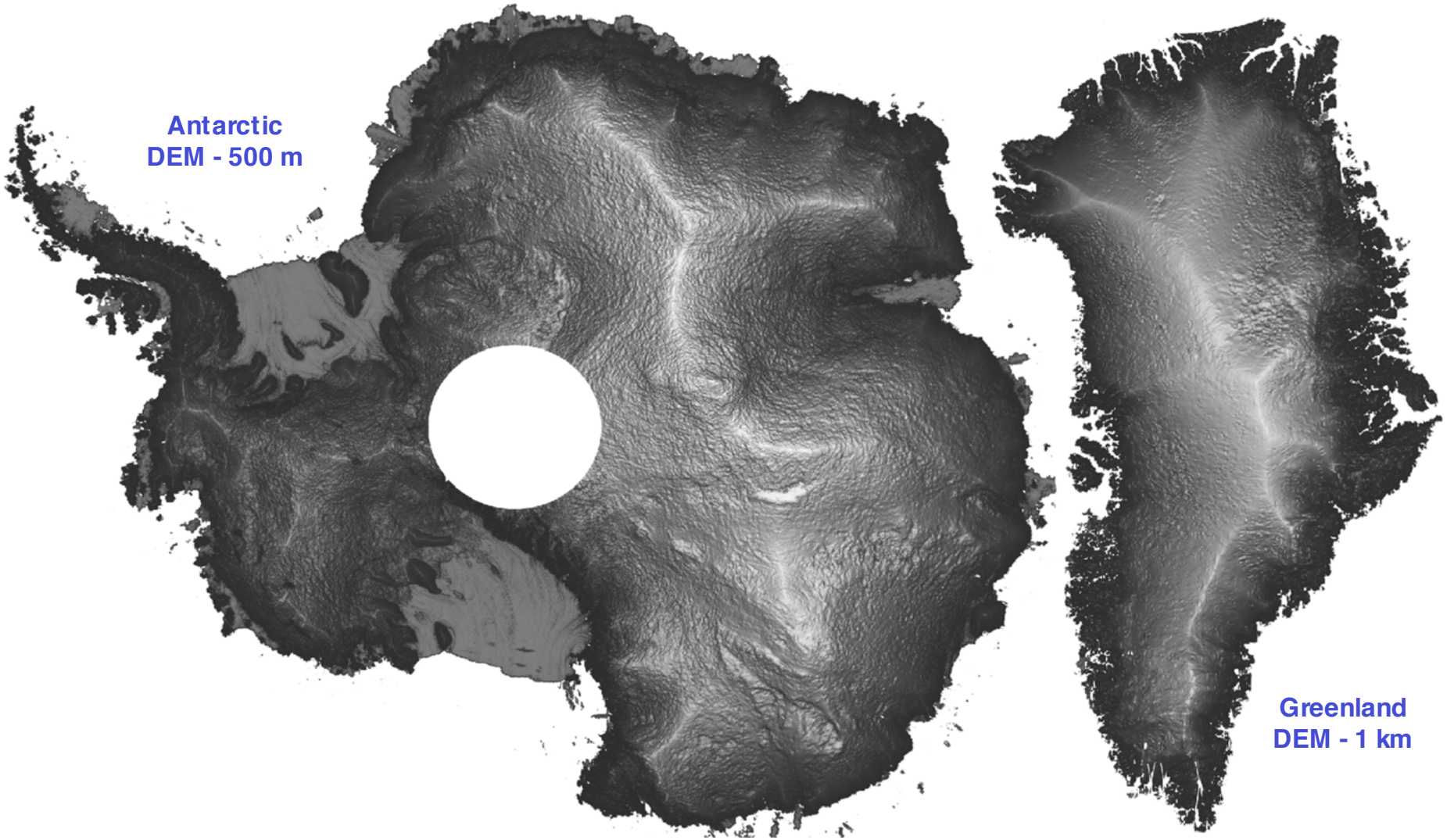
ICESat elevation height & rms deviation across icesheet above Lake Vostok.

Rms value of < **2.5 cm** for individual elevation measurements is GLAS range precision.



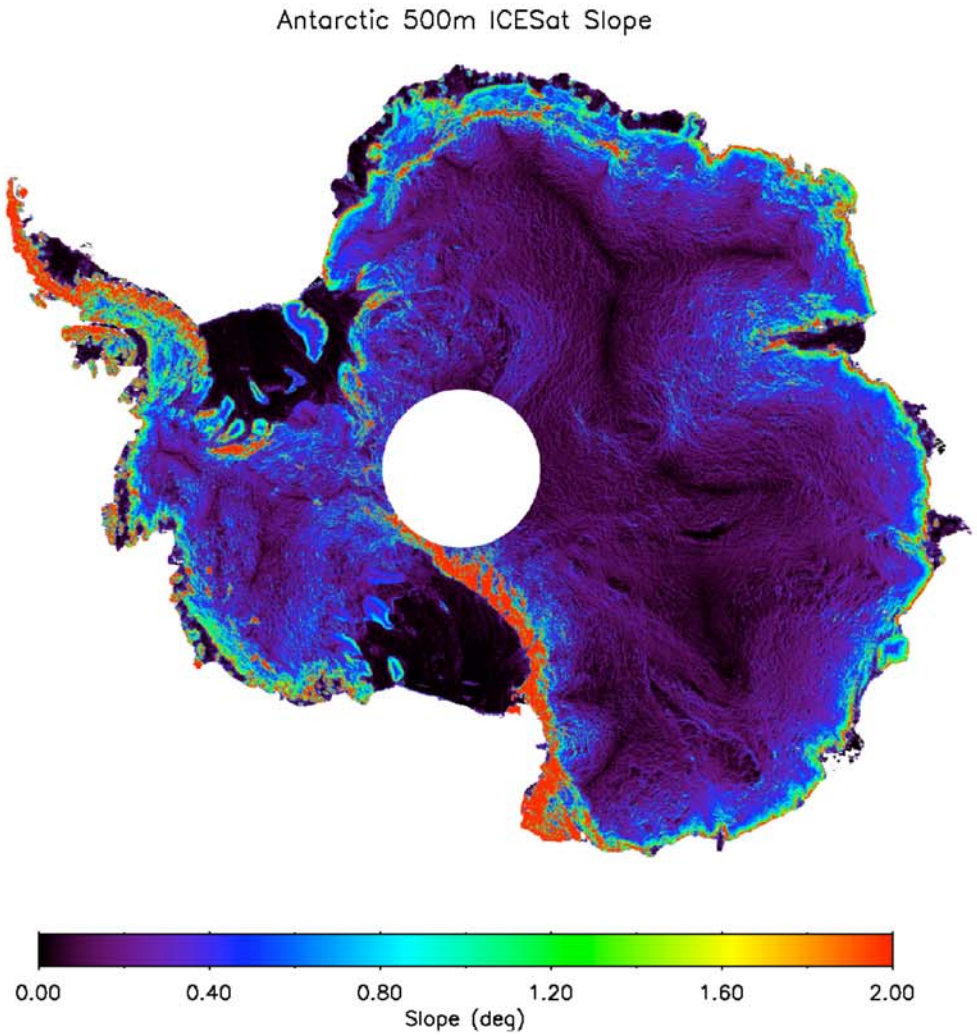
C. Shuman et al

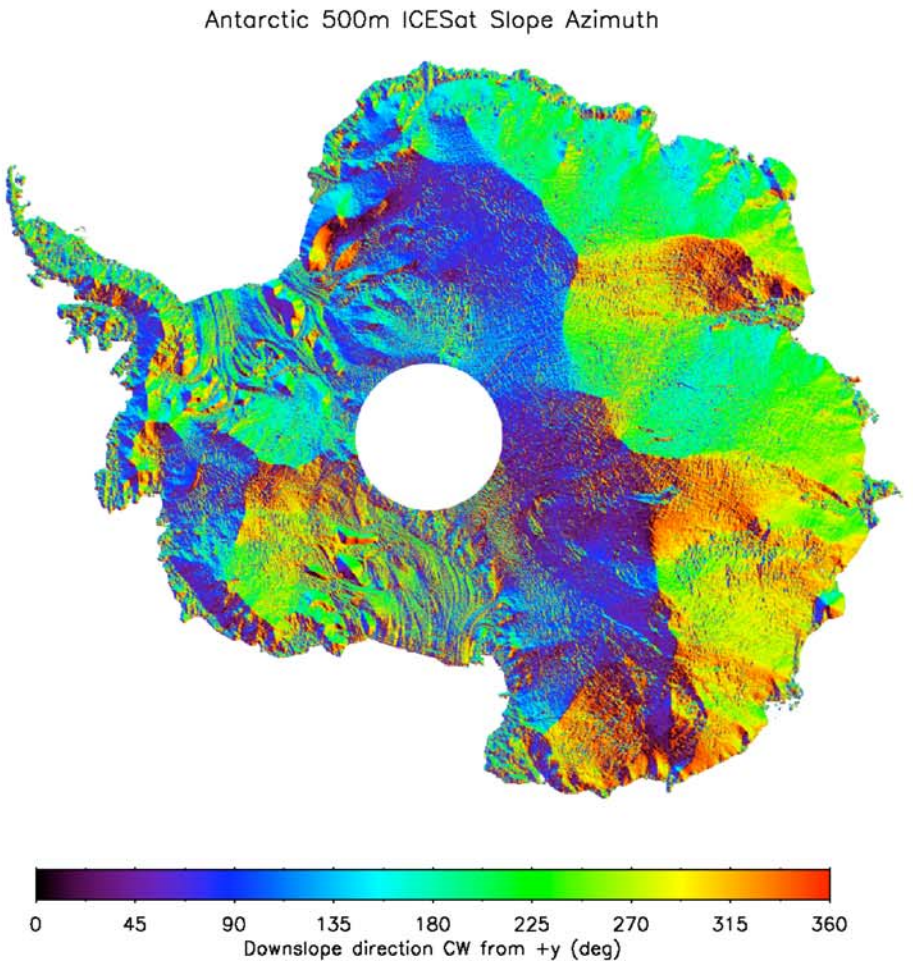
4. DEMs Based on ICESat Measurements



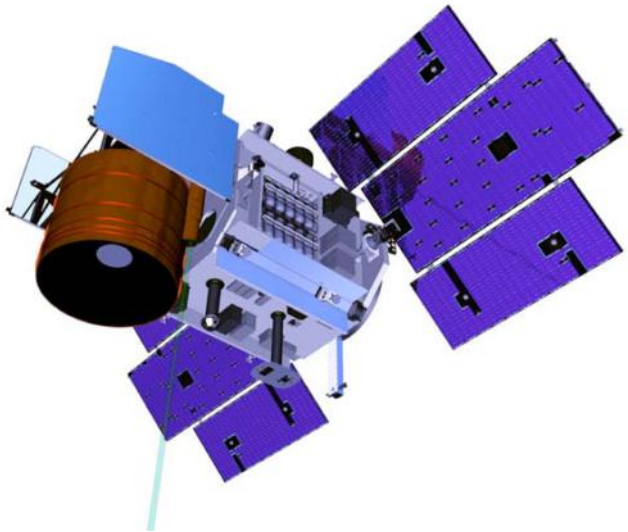
C51B-0276 - Digital Elevation Models of the Antarctic and Greenland Ice Sheets from ICESat, J.P. DiMarzio et al.

4. Antarctica Slopes from ICESat



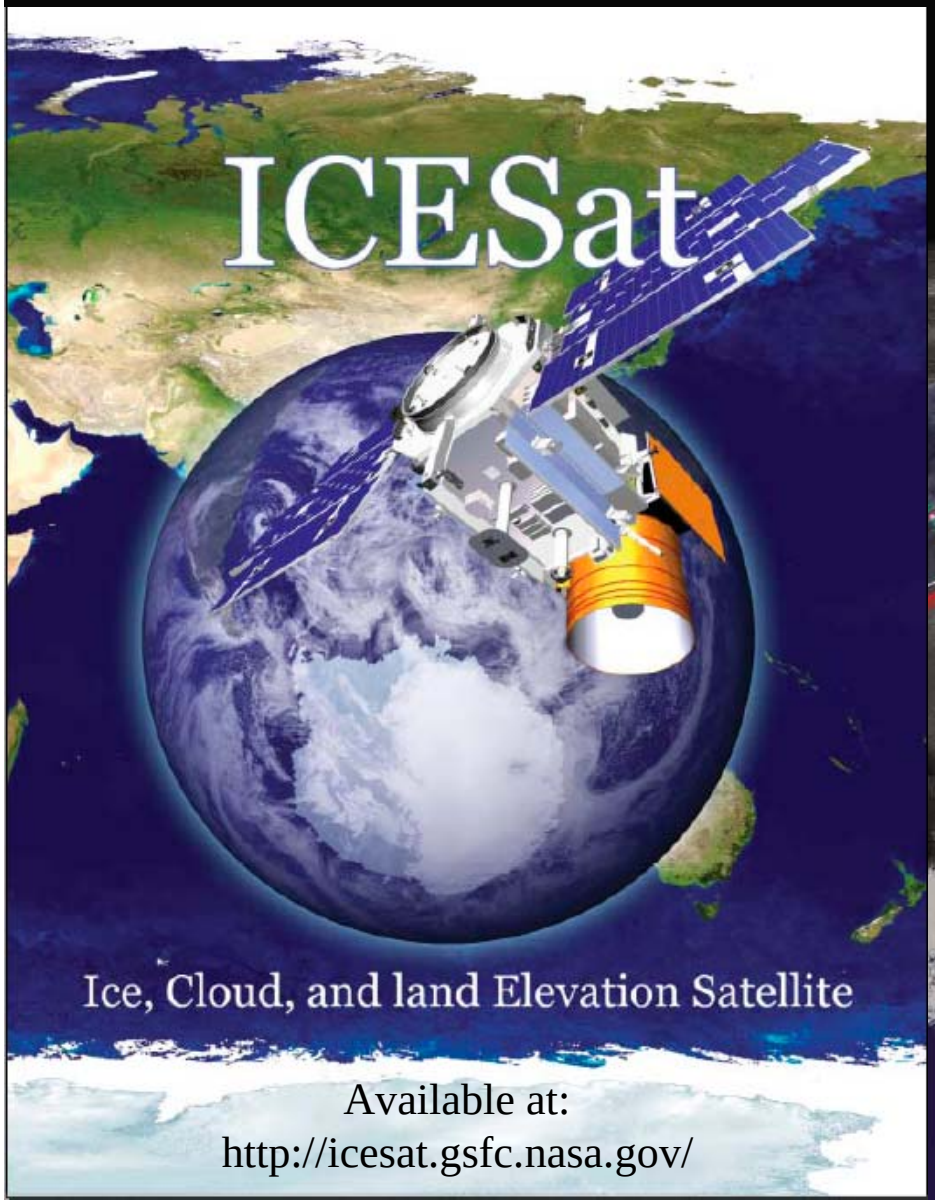


4. Summary

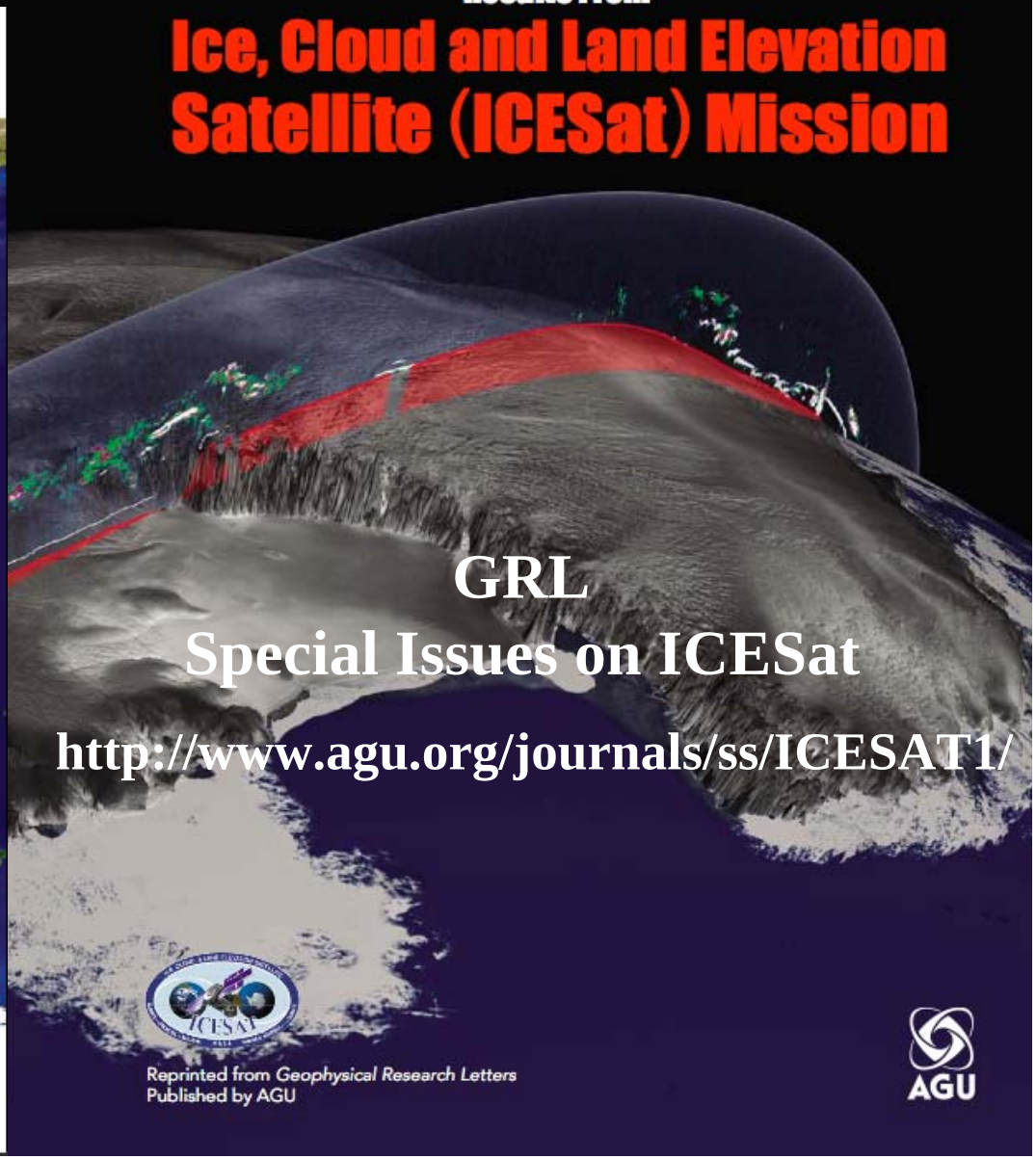


- GLAS has advanced the state-of-the-art for space lidar
  - Completed: > 1.3 billion measurements, 10 campaigns
  - Unprecedented 3 cm vertical resolution from space
  - New capability for Earth science (multi-disciplines)
  - 30 scientific papers so far
- If laser energy trends continue:
  - Laser 3 Energy for 4-5 more campaigns (end 4th year, Nov. 2007)
  - Should meet ICEsat mission's primary science requirements
- Also has highlighted some remaining laser technology needs:
  - Diode array parts quality
  - Better understanding physical processes which occur inside space lasers
    - Particularly slow changes over long time scales
  - Laser architectures which are more robust against parts and process issues

5. More Information



Available at:
http://icesat.gsfc.nasa.gov/

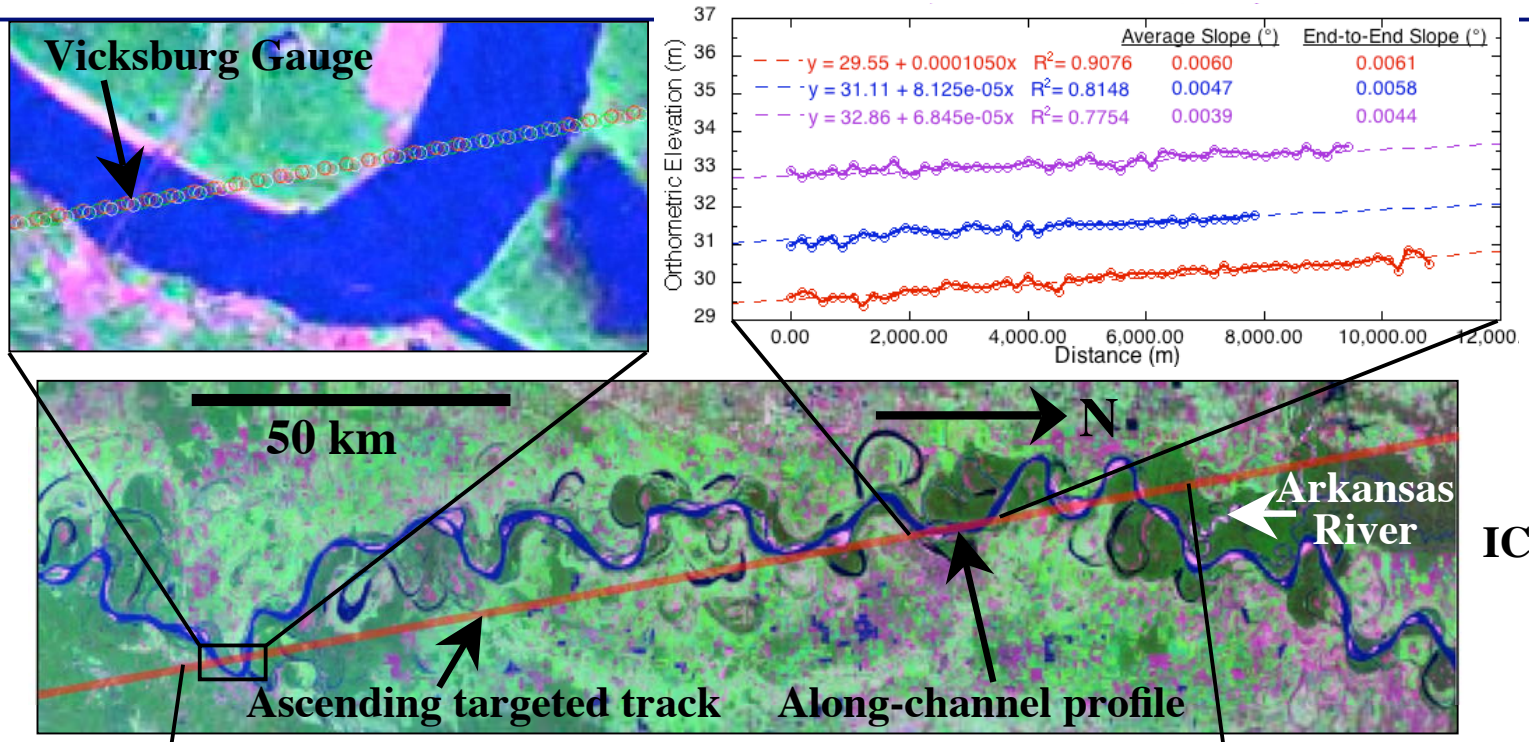


GRL
Special Issues on ICESat

http://www.agu.org/journals/ss/ICESAT1/

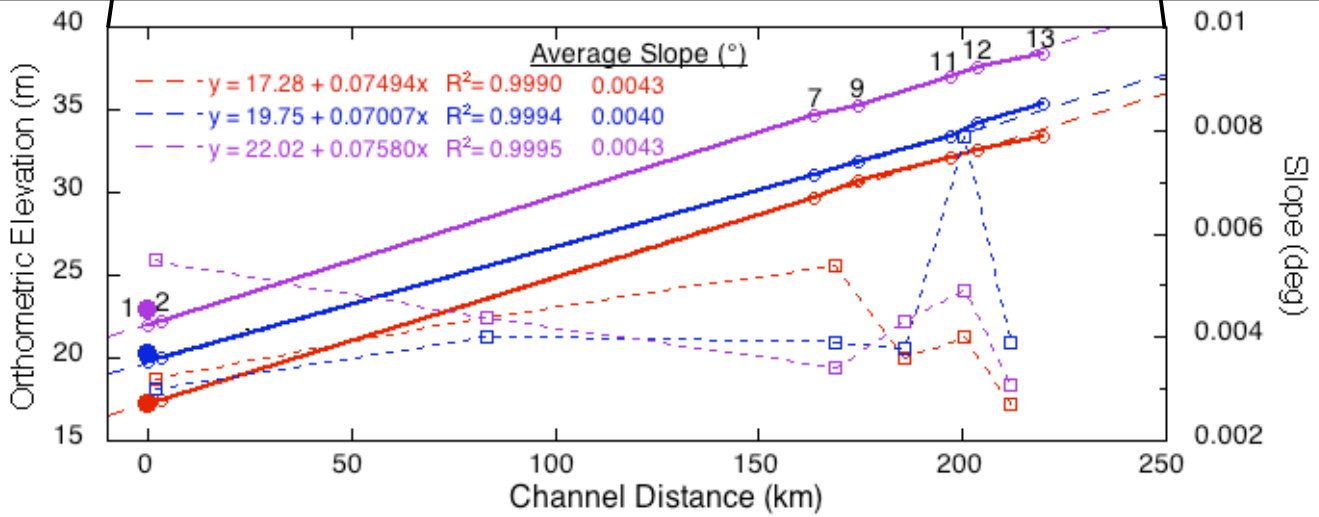
Backup

2. ICESat Profiles of the Lower Mississippi River



ICESat Footprint Elevations along Straight Reach and Derived Slopes

Orange: ICESat Targeted Profile on Landsat Image



River Stage at Channel Crossings and Derived Slopes

Vicksburg Gauge — ICESat Average

- Oct. 2, 2003
- March 6, 2004
- June 5, 2004

Harding et al., *Eos Trans. AGU*, 85(47), C21B-05, 2004.

Whiskers of Tin-Lead (Sn-Pb)
on REFLOWED Die Attach Solder
Used in the Manufacture of a
Laser Diode Array

Working Hypothesis:
Tin-Lead Whiskers from Diode Array

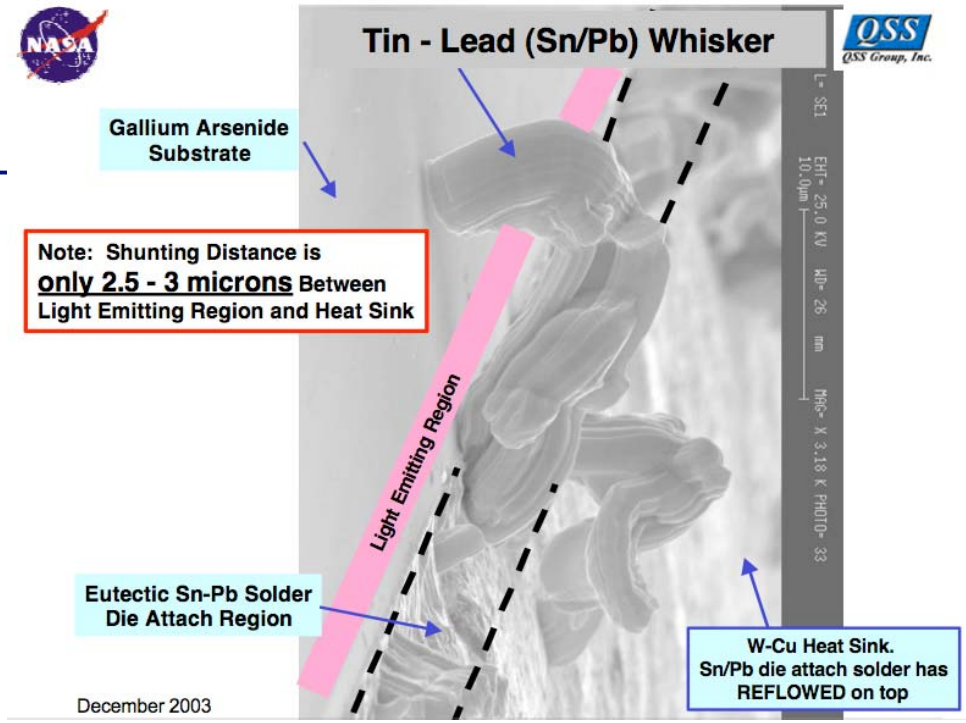
20 microns

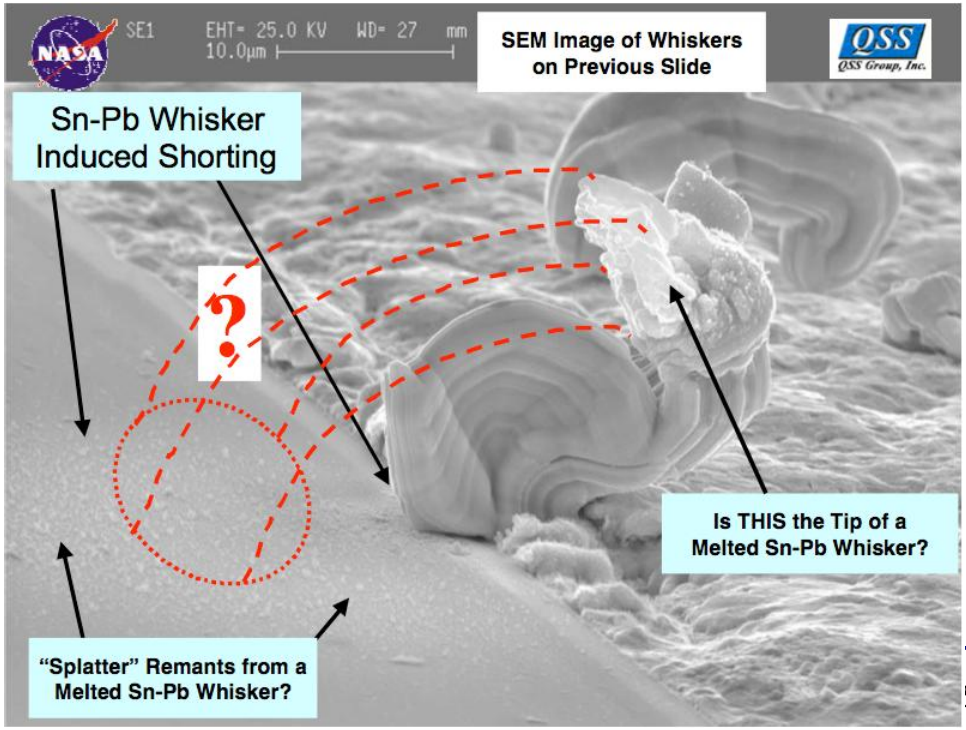
December 2003

Images/Failure Analysis Provided by
Dr. Henning Leidecker/NASA Goddard Space Flight Center
Chris Greenwell/QSS Group, Inc.

Compiled by
Jay Brusse/QSS Group, Inc.

MOLA laser
Flight spare SDL
G9 pump array





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NASA Goddard Tin (and Other Metal) Whisker WWW Site
http://nepp.nasa.gov/whisker